# A Space Based Radar Antenna Concept to Counter Camouflage and Concealment

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## *ABSTRACT*

*This paper presents a novel concept for a low-mass 50m² deployable P-Band dual polarisation antenna, noting that P-Band observations can penetrate dense forests, enable searches for buildings or vehicles hidden beneath forest canopies, and possibly penetrate the earth to support searches for tunnels and caves. P-Band is important because existing optical or radar instruments cannot penetrate the forest canopy or the earth's surface in order to monitor suspicious activities. The average boreal forest density is estimated to be 50 tons/ha, with maximum densities of 120 tons/ha. Existing space based Synthetic Aperture Radar (SAR) systems operate at too high a frequency (X- and C-Band) and the transmitted signals literally bounce off the canopy of these forests. Only with radars operating at P-Band or below can adequate penetration of these forests be achieved.*

*The antenna is designed to be used from a spacecraft in a low-Earth orbit. The antenna design has a monolithic array of feed and radiating patches bonded to a transversally curved structure consisting of two Kevlar sheets. The first sheet supports the array and the other sheet supports a ground plane. The two sheets are connected by a compliant Kevlar core that allows the whole structure to be folded elastically and to spring back without damage to its original shape on release. This structural concept has been given the acronym of FLATS (Folding Large Antenna Tape Spring). Test-pieces have been made to demonstrate both the RF and mechanical aspects of the design, particularly the RF performance before and after folding the structure. It is concluded that the proposed concept is the design with the highest potential for large low frequency antennas for low-cost missions.*

*The difficulty facing the SAR system designer is that existing instruments at C-Band (5.3 GHz) already use antennas with areas greater than 10 m², and to maintain the same SAR performance, the antenna area varies inversely with frequency. Thus, at P-Band (0.435 GHz) an antenna of 50 to 100 m² has to be launched and deployed in space. It is this packaging and structural problem and its unique solution that are the subject of this paper.*

## 1.0 INTRODUCTION

Global surveillance is a key parameter in achieving international security. Hostile elements respond to surveillance efforts with the use of camouflage and concealment, thus nullifying the use of optical observations and existing radar observations. Current space based Synthetic Aperture Radar (SAR)

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systems, such as ASAR, ERS-2 and Radarsat-1, operate at too high a frequency (C-Band) to penetrate into and beneath the canopy of dense forests. The average boreal forest density is estimated to be 50 tons/ha, with maximum densities of 120 tons/ha. Figure 1 shows that only with radars operating at or below P-Band can adequate penetration of these forests be achieved, enabling searches for buildings or vehicles hidden beneath forest canopies, and possibly penetration of the ground to support searches for tunnels and caves.

The difficulty facing the SAR system designer is that existing instruments at C-Band (5.3 GHz) are already over 10 $m^2$ and to maintain the same SAR performance the antenna area needs to increase linearly as the frequency decreases. Thus, at P-Band (0.435 GHz) an antenna of 100 $m^2$ is required to be launched and deployed in space. It is this packaging and structural problem and its unique solution that are the main subject of this paper.

An additional problem when operating space based radar at low frequency is the impact of ionospheric conditions on propagation including the effects of Faraday Rotation on polarimetric purity, and of ionospheric scintillation on focussing. This paper also investigates this impact and proposes the best solution to overcome the phenomena.

Interest in the potential to make such observations from space increased substantially during 2003 when the WARC granted an allocation to operate space-based radars between 432 and 438MHz with Secondary User status.

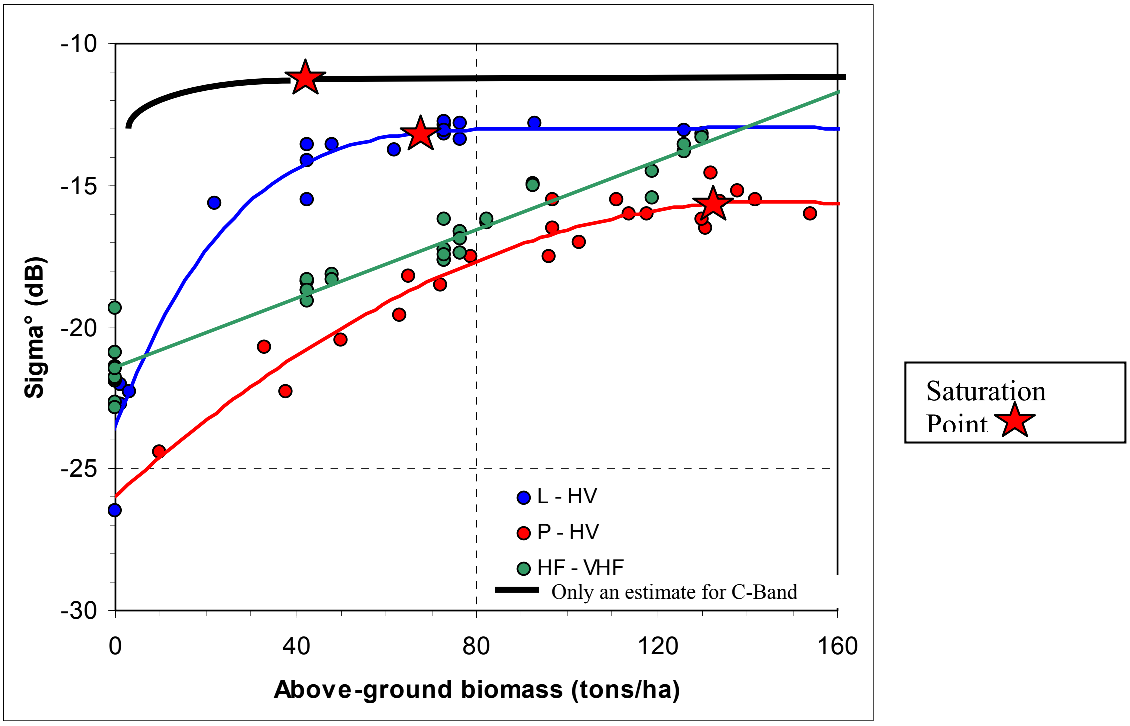



**Figure 1 Strength of signal reflected off vegetation of different density**

## 2.0 IONOSPHERIC ISSUES

Ionospheric effects influence the ability to focus low frequency SAR echo data, and when coupled with the Earth's magnetic field and particular directions of observation, cause polarisation plane rotation (Faraday Rotation).

At maximum TEC (Total Electron Count), range and azimuth resolution may be severely degraded. The effect scales with bandwidth and frequency. In addition to the resolution degradation, the sidelobe ratios also degrade, the peak offset increases and the peak gain decreases with increasing TEC value. However, the narrow bandwidth allocation from ITU at P-band and the relatively coarse azimuth resolution alleviate much of the focussing problems, except during the most extreme ionospheric conditions. Three autofocussing techniques have been briefly described and can be applied to correct data suffering from azimuth resolution degradation and may also provide a means of quantifying the within-image TEC variation.

Faraday Rotation (FR) affects the illuminating radar beam by rotating the plane of polarisation of both transmitted and scattered signals in the same rotational sense. It therefore exacerbates the rotation effect rather than cancelling it, and the magnitude of plane rotations experienced for a given set of ionospheric conditions is about ten times greater at P-band than at L-band. Further work is necessary to quantify the likely short term (i.e. daily and within image) temporal variations of TEC around these mean values and there is a need to quantify scintillation effects at the sub-100 km scale. In general with P-band operation, a Faraday Rotation correction methodology will be required.

Examples of FR predictions at low and high levels of Sun-spot activity are presented in Figure 2.

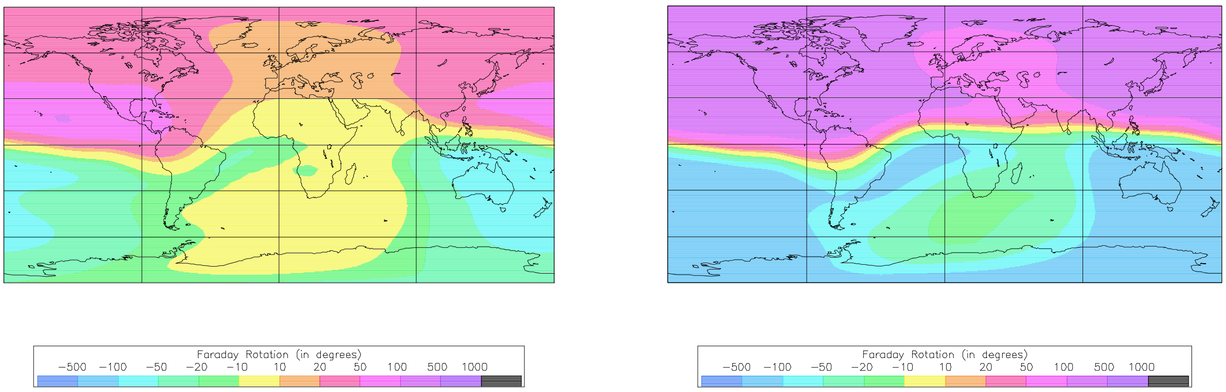



**Figure 2 Prediction at 0 UT for Low Sunspot number (left) and High Sunspot number (right).**

Although open loop correction of L-band fully polarimetric data can be achieved using TEC measurements from an independent source in the ground processing, a more robust method using fully coherent quad polar observations is preferred. A possible hardware solution to FR mitigation is pre-rotation of the transmit polarisation to that value Ω which minimises on-board the cross-correlation between the H and V channels. However, such a hardware solution increases system design complexity and additionally, on-board calculation of Ω places strenuous requirements on the hardware, requiring minimal cross-talk and channel imbalance. The current recommendation is the use of fully coherent quad polar observations in order to measure the amount of rotation and correct for it.

The study examined circular polarisation as a FR mitigation technique but noted that knowledge about sensitivity to geophysical parameters is scant. An initial analysis was not encouraging, but indicated that

further work would need to be performed to verify the strength of relationship between circular polarised SAR data and geophysical parameters.

## 3.0 ANTENNA REQUIREMENTS AND PROPOSED APPROACH

The observational requirements and the resulting RF design and analysis indicated that a 50 m² antenna at P-Band in a LEO of approx. 630 km could provide an instrument that could penetrate the densest forests. This antenna would only be able to electronically scan between 20 and 30 degrees off Nadir in Quad Polar mode, instead of the 20 to 40 degrees achievable with a 100 m² antenna. However, this only affects the time taken to achieve global access by a few days (from 11-days to 20-days) and not the quality of the data, hence was deemed acceptable. The antenna requirements affecting the design are listed below;

- P-Band antenna operating at 0.435 GHz.
- Quad Polar operation, transmitting and receiving on both H- and V- polarisations, hence requiring two independent feed systems.
- 50 $m^2$ with a height of 2.82 m and a length of 17.29 m.
- Deployed frequency of at least 0.5 Hz, but ideally around 1 Hz, in order to achieve sufficient stiffness.
- Deployed antenna planarity better than 40 mm.
- Stowed packaging to allow launch on a low cost launch vehicle (Rockot, Vega or Soyuz).
- Low mass design, in order to be compatible with the launch vehicles, hence a mass target of less than 1 $kg/m^2$

RF design options already in use for higher frequency SAR antennas include slotted waveguide (ERS-1 and 2 and Radarsat-1) and active phased arrays (ASAR and Radarsat-2). A trade-off looked at the packaging (stowing and deploying) of these types of RF solution to determine what was viable and realistic for low frequency SAR applications. The slotted waveguide solutions were ruled out due to the size of the P-Band waveguide even though collapsible options were reviewed, see Figure 3. In the past, phased array antenna designs have relied on splitting the antenna length into separate panels which are then folded onto each other in order to produce a smaller panel stack, though adding deployment complications, mass and cost, see Figure 4.

**Figure 3 P-Band Waveguide Solutions**

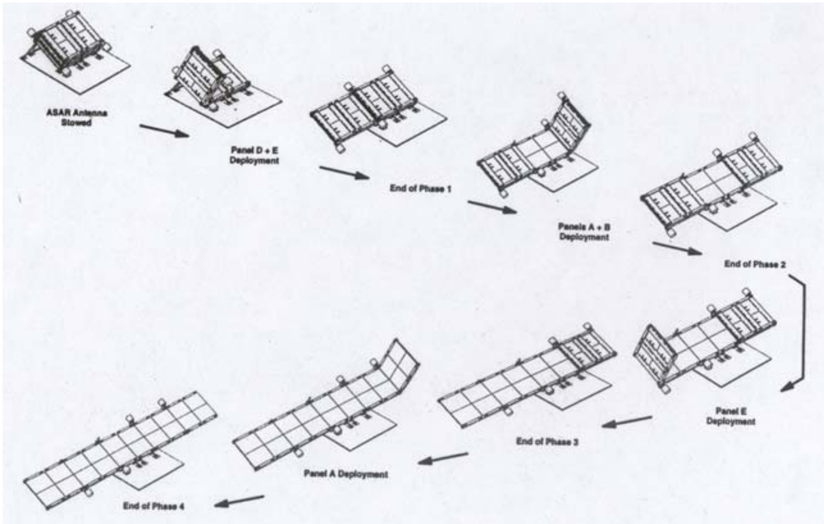



**Figure 4 Active array antenna (ASAR) stowed to deployed (Courtesy of Ref. [1])**

The design solution with the highest score from the trade-off exercise was that of a monolithic array with 5-rows of 28 radiating elements per row, see Figure 5, based on a Folding Large Antenna Tape Spring (FLATS) structure. It is this FLATS technology that is presented in this paper. The design solution is shown stowed and deployed on a satellite in Figure 6.

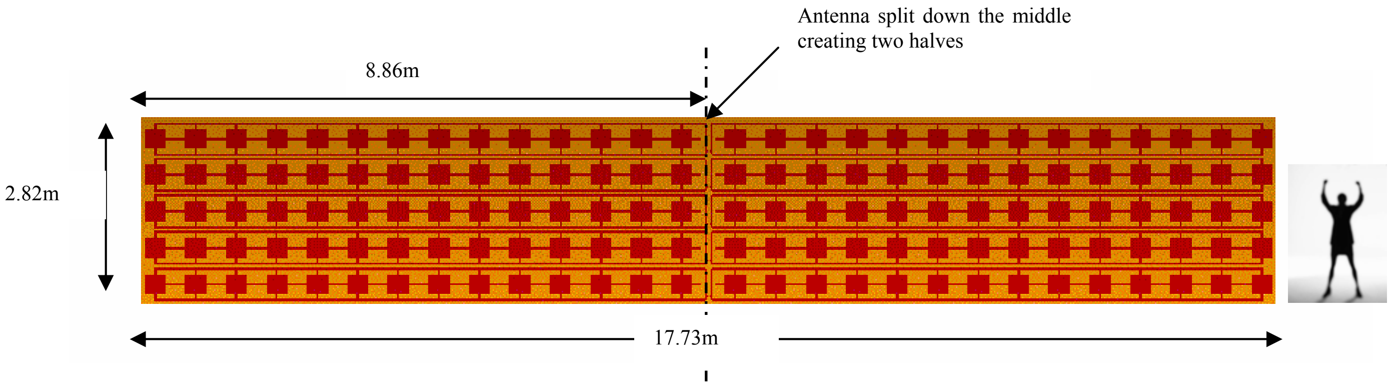
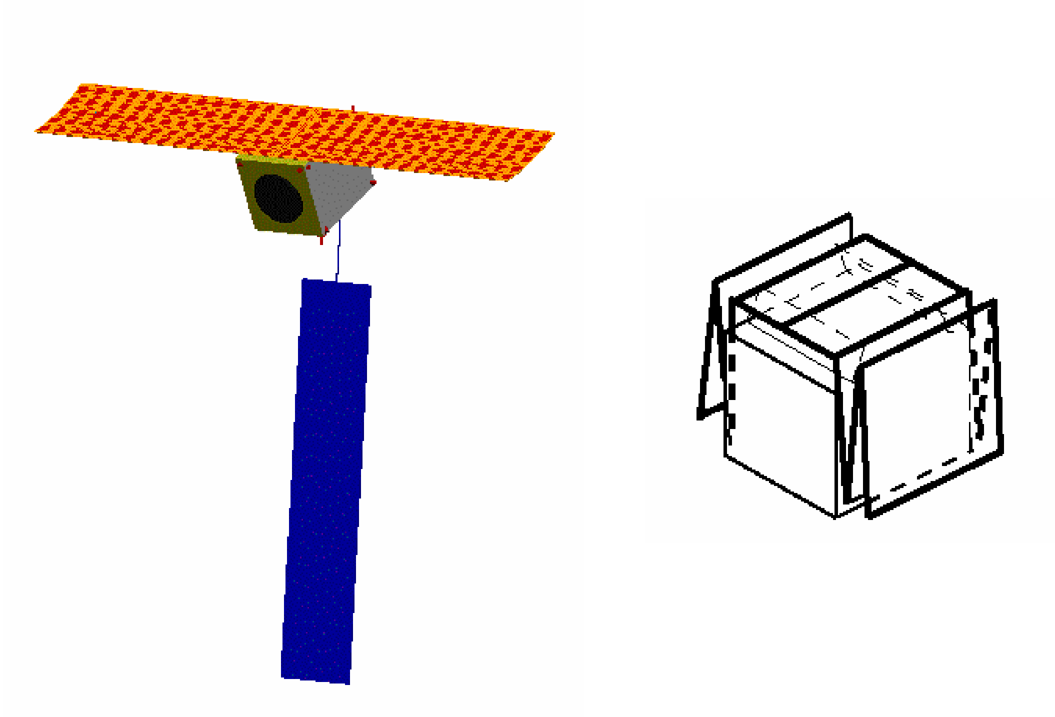



**Figure 5 Monolithic P-band Antenna**



(a) (b)

**Figure 6 (a) Arrangement on spacecraft of monolithic array antenna and (b) packaging scheme**

This paper now summarises the mechanical design of the full 50 m$^2$ P-band antenna as well as the design, manufacturing and testing of a test-piece.

## 4.0 RF DESIGN

In principle and from a manufacturing perspective, the fabrication of a phased array antenna by printing all of the radiators and feed lines on a single deployable membrane is the simplest and lowest-cost option and is well suited for use at P-band because the dimensions are large enough to effectively eliminate tolerance problems and transmission losses are quite low.

While it is customary to describe the monolithic antenna as 'planar', the low profile laminated construction is easily converted to a cylindrical surface, such as may be required to promote surface rigidity or to be conformal to an existing backing structure. Under such conditions, the same RF design procedure can be applied as that used for the planar geometry, provided the radius of curvature of the array is much greater than the wavelength, and the sub-array rows are aligned with the cylindrical axis.

Building on the balanced-feed concept, the 'unit radiator' design shown in Figure 7 has been proposed as a means of reducing the radiated cross-polarisation from feed-network line currents. It can be appreciated that, due to symmetry, the HP feed will radiate zero cross-polar and have zero aggregate coupling to the balanced VP feed line. Any cross-polar radiated by the balanced VP feed line system will, as stated above, cancel on boresight – although the associated lobes may appear at wider angles.

The high inherent isolation between the V and H operating modes does allow a certain amount of design optimisation on an independent basis. However, for larger arrays, a full wave analysis of the complete dual-polarised structure does become necessary in order to model all possible coupling mechanisms. The radiation patterns associated with a surface fed single layer RF structure are shown in Figure 8 and, although satisfactory, better performance is anticipated from a potential improvement in the present design. Such an improvement is currently being investigated. The new design is based on a 2-layer structure in which separate HP and VP arrays are etched on either side of the upper Kapton membrane. This removes the direct conductive link between the layers and also provides additional optimisation parameters to help enhance performance.

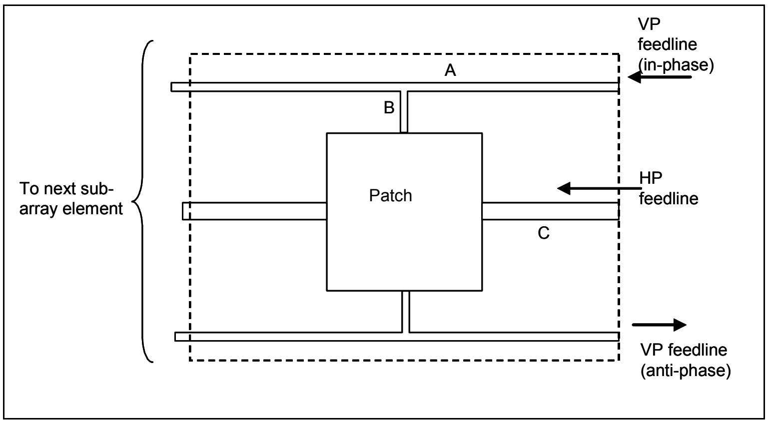



**Figure 7 Proposed Dual-Polarised Sub-Array Element 'Cell'**

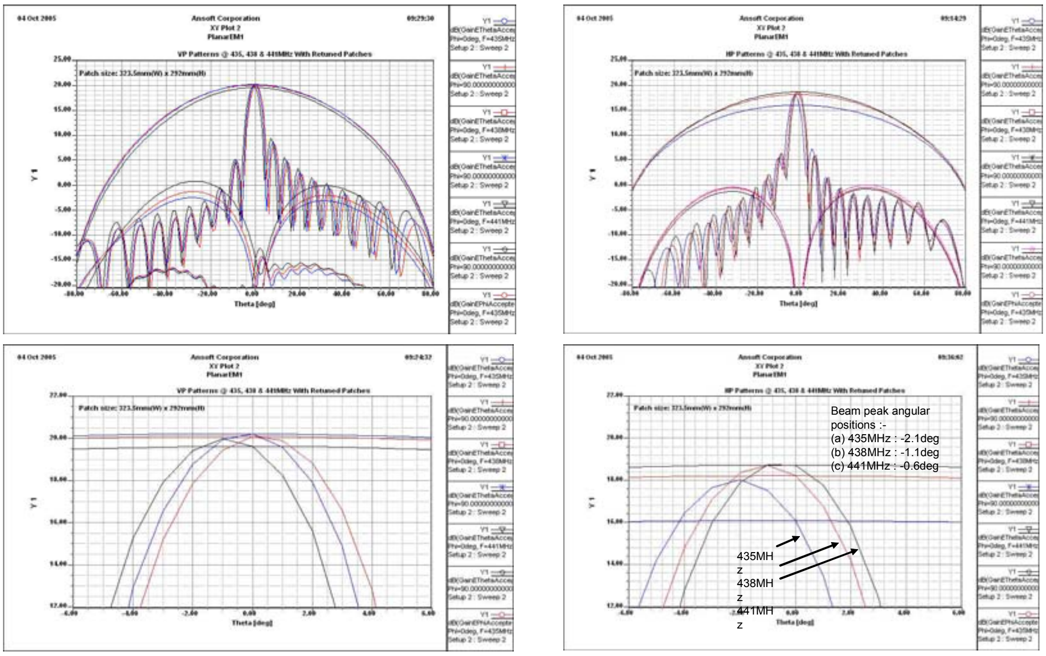



**Figure 8 Azimuth Pattern cuts for an 11-element Dual Polarised Array**

## 5.0 Mechanical Design

### 5.1 Monolithic design based on a FLATS Curved Surface

The basic concept, shown in , is a transversally curved sandwich plate structure forming a giant tape-spring. Tape springs are well known in the field of deployable structures.[2,3] They have the unique feature that their curved shape provides a significant increase in bending stiffness compared to a flat plate, yet once the transverse curvature has been removed, a tape-spring can be easily folded.

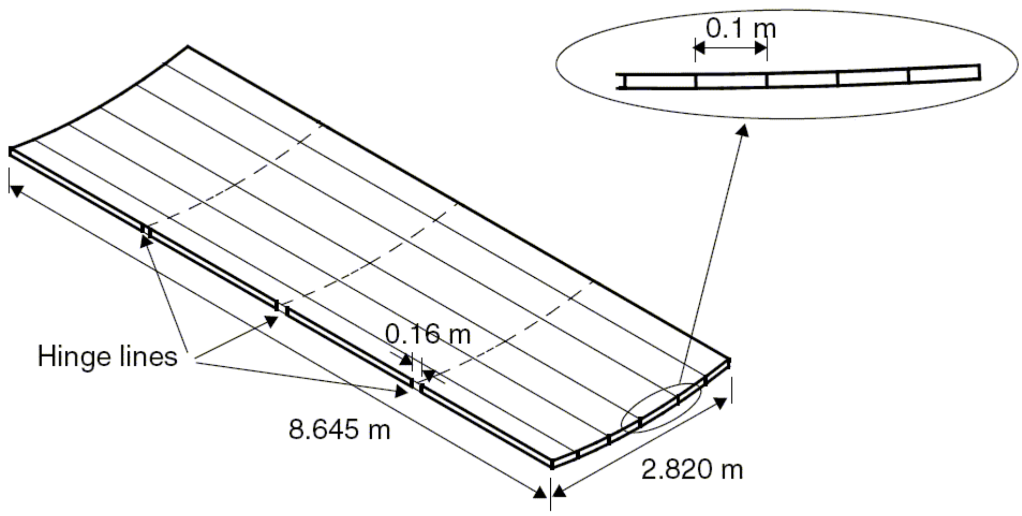



**Figure 9 FLATS concept (single wing)**

A single sheet tape-spring with dimensions of 2.82 m by 8.64 m would never be stiff enough, however, the RF design requires two sheets 20 mm apart, the ground plane being the second sheet. By joining together the two sheets with a core structure an efficient structural design is obtained. Of course, a standard sandwich plate with this shape would be very stiff, and hence it would not be possible to fold it. To overcome this, the core of the proposed structure consists of longitudinal ribs, but no transverse ribs.

Note that this structural concept provides a curved array rather than a planar array, however, a planar RF beam can be obtained by phase correction for each row power source. The transverse curvature of the array is not detrimental to the planarity specification, which, given the curved nature of the proposed solutions, really ought to be termed a *surface accuracy requirement*, not a planarity requirement.

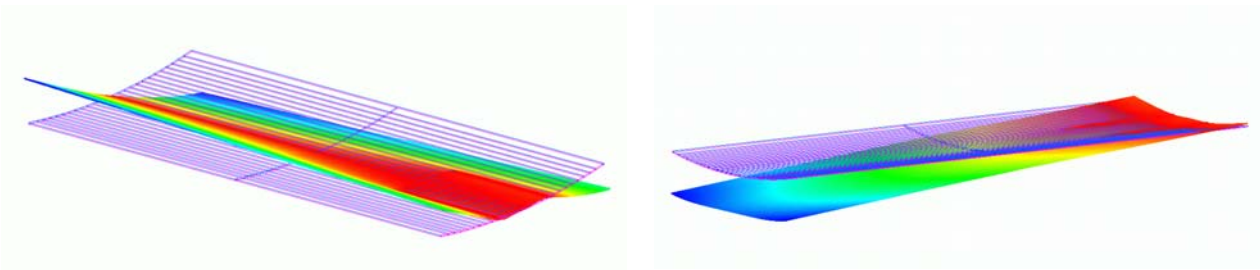
Thus, the structure consists of two curved cylindrical face-sheets 20 mm apart, with internal unidirectional ribbing, strengthening the longitudinal direction of the antenna. The structure can be folded at hinge-lines where the internal ribs have been removed, while the face-sheets bend to a compliant hinge similar to that seen in a steel tape measure. The structure is stress free when deployed, hence the stowing (flattening and folding) of the structure stores potential energy to create a self deploying structure.

The curved nature of the deployed structure allows it to lock into the desired shape on deployment. Designed as a Monolithic SAR, one skin acts as the ground plane and the other skin as the feed and radiating patches. The nature of the structure allows continuous RF paths, even across the pseudo hinge-lines. The radiating rows run in straight lines down the cylindrical shape. The material between the patches and the ground-plane must be RF transparent, hence Kevlar has been chosen.

## 5.2 Structural Analysis

One wing of the deployed structure was analysed using a finite element model consisting of thin shell elements. The analysis showed that with a 4-ply plain-weave Kevlar lay-up for each skin and unidirectional ribs spaced approximately every 100 mm, the deployed fundamental natural frequency of vibration was about 0.9 Hz, see Figure 10(a), which is above the 0.5 Hz minimum requirement and acceptably close to the 1 Hz goal. The model was constrained at 4 points, at the ends of the external support ribs that attach the antenna to the platform.

The predicted mass of the structure was 1 kg/m2, while the load required to flatten one wing was predicted to be 160 N applied along the edges of the antenna. This results in stresses of only 12 MPa (with 500 MPa at a strain of 1.4% being the ultimate strength, 120 MPa at a strain of 0.3% the tensile yield and 60 MPa at a strain of 0.2% the compressive yield).



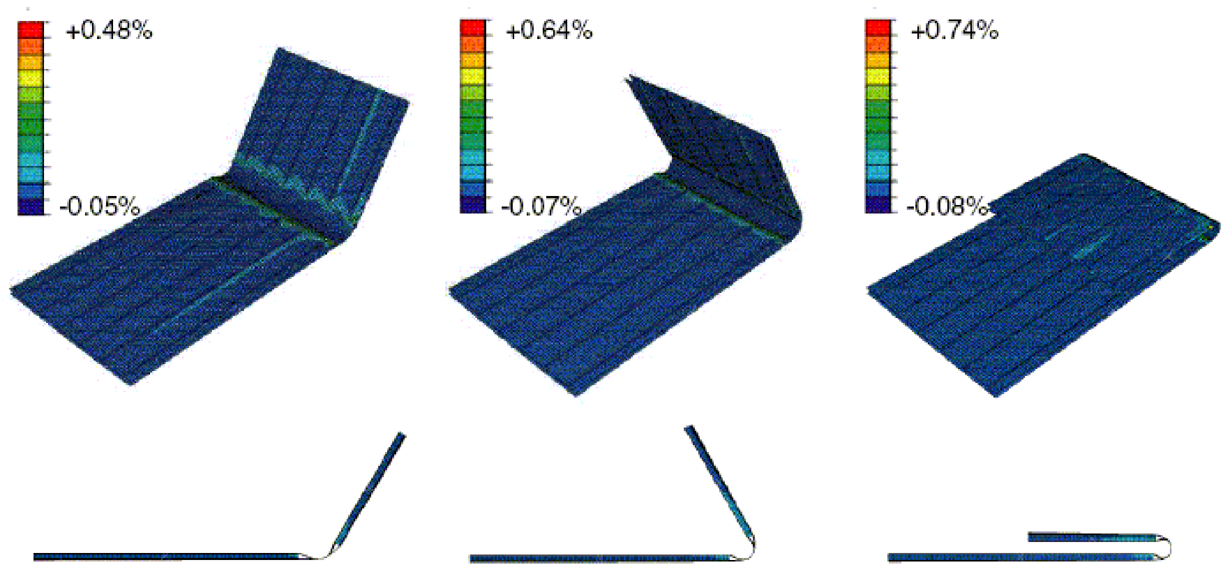
(a) (b)

**Figure 10 Natural modes of deployed half wing: (a) twisting mode at 0.9 Hz; (b) bending mode at 0.94 Hz**

Structural analysis has been performed to predict the fundamental natural frequency of vibration of the stowed panels and from this the maximum panel displacement during launch. The analysis predicted a frequency of 10 Hz for the fully stowed antenna and, assuming typical design accelerations of 20 'g', the maximum panel deflection would be 50 mm assuming linear behaviour. However, at this low frequency non-linear effects take over and so the maximum displacement is expected to be less than 10 mm.

An analysis of a test-piece using a finer mesh was carried out with the ABAQUS finite-element package,[4] again concentrating on the hinge-line folding process. The process is in two steps: flattening and "Z" folding. Flattening is simulated by fixing one longitudinal edge of the structure and pulling the other edge away from it. At this point the structure is not completely flat, but it is sufficiently flat for the next stage of the simulation, which involves longitudinal folding, to be conducted successfully. The strain levels after flattening are insignificant. The formation of a longitudinal fold involves contact between the two skins in the hinge line region: frictionless hard-contact with finite sliding is assumed. The simulation of longitudinal folding is in two stages. First, one part of the structure is rotated 180° while the other end is not allowed to move. Second, the moving part is pushed down against the fixed part, to tighten the fold region and so package the structure more compactly.

(a-c) show contour plots of the maximum in-plane principal strains during the first stage. The maximum strain is 0.74%, and occurs in a region of the inner skin, just at the inner end of the ribs.




| | | |
|---|---|---|
| (a) | (b) | (c) |

**Figure 11 Folding simulation: (a) 60 deg. folded; (b) 120 deg. folded; (c) 180 deg. Folded**

# 6.0 MANUFACTURING

## 6.1 Test Pieces

Two test pieces of one row each were manufactured as shown in Figure 12 and Figure 13.

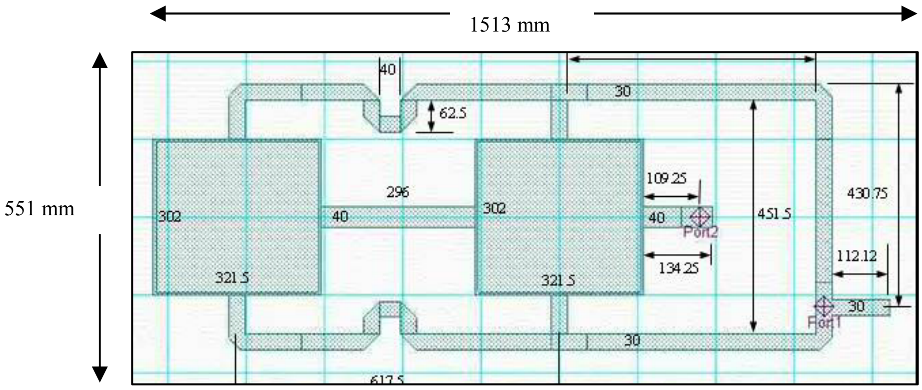



**Figure 12 Test Piece RF Circuit**

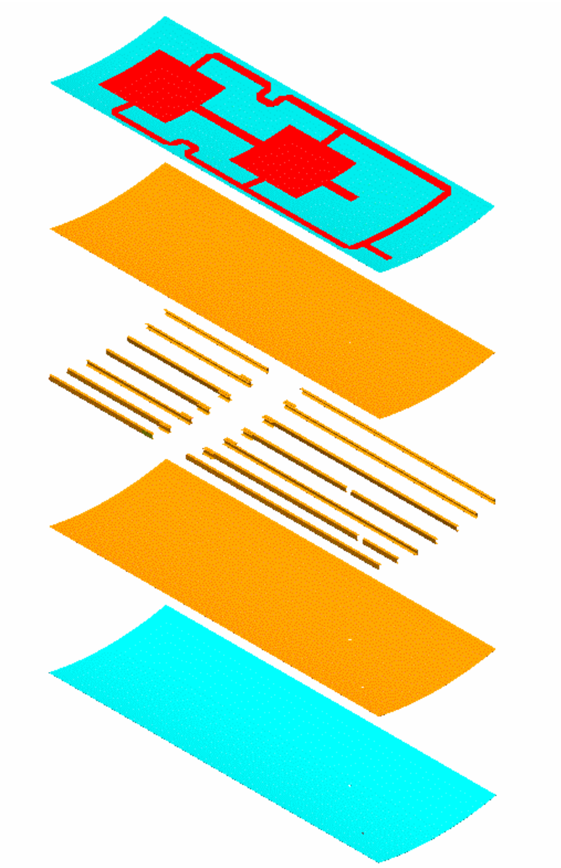
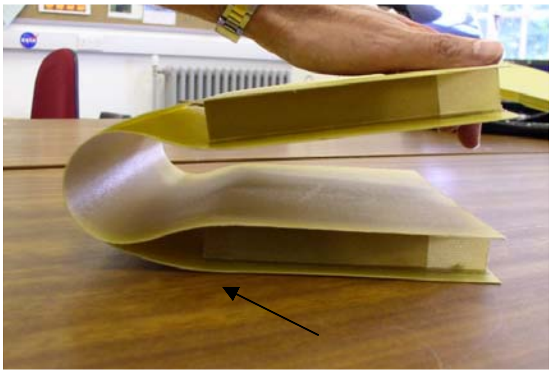


**Figure 13 Test Piece exploded view showing construction**

In addition to these large test pieces some sample hinge-lines were made. Two hinge-line models were made from 3-ply and 4-ply lay-ups respectively. These models had different ply thicknesses in order to investigate which was best for the main test-pieces. The 4-ply required more force to bend the hinge, thus creating more pressure on the internal ribs. The 3-ply design naturally is less stiff, requiring less force to bend the hinge, thus applies less pressure to the internal ribs.

After bending the 4-ply sample 180 deg. to a radius of approximately 30 mm, and then straightening, the deformation of the material was not fully recovered, Figure 14. It was concluded that the Kevlar had been taken beyond its compressive yield limit. This was subsequently confirmed by an analysis of the stresses involved in the bending of a hinge, using the limiting values quoted in Section 3-3.2. The solution was to reduce the stresses in the skin during bending by reducing the skin thickness to the 3-ply design and limit the bend radii to 40 mm, by using spacers.



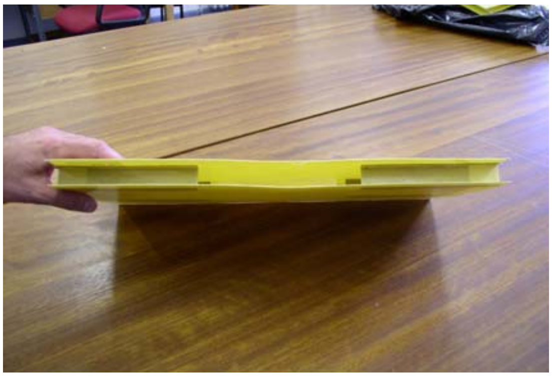


**Figure 14 Hinge-line model with 4-ply layup showing residual deformation after bending**

## 6.2 Mould Tool

The main test-pieces require curved skins to produce the tape-spring effect. Initially, a flat sheet of stainless steel under 3-point bending was used as the mould tool, but this was later replaced with a 4-point bending configuration using two tubes. The improved tool is shown in Figure 15.

**Figure 15 Mould Tool used for second structure**

## 6.3 First Test Piece

The first test piece was manufactured on the initial mould tool and had only 4 internal ribs, to avoid them interfering with the RF connections. However, the unsupported span was too great, leading to poor control of the gap between the skins.

However, this structure has been folded and unfolded 6 times. Figure 16 shows the hinge-line when the structure is folded into its stowed state. Note that whereas the curved structure flattens, the ribs do not, hence the structure goes from a 20 mm thick curved structure to a 20 mm thick flat structure.

**Figure 16 Hinge-line when Antenna stowed**

The structural analysis has shown that using 3-ply Kevlar the rigid panel sections on either side of the hinge-line should not be brought into contact when the antenna is stowed, otherwise the bend radii will be too tight and the skin material will permanently deform. Therefore, spacers should be used to maintain the appropriate gap and bend radii. These spacers can be used as hard points to hold the stowed structure. An initial design is for 4 cup and cone standoffs with 50 mm diameter and 40 mm height. This not only provides the required radii but also provides dynamic clearance for the launch load deflections.

This first structure was used in the assembly of the first test-piece, see Figure 17. This assembly was range tested for antenna pattern, gain, and cross polar isolation. The antenna was then folded and unfolded and retested and showed no changes in RF performance.

(a) (b)

**Figure 17 First test-piece (a) hung for display (b) showing connectors at the back**

## 6.4 Second Test Piece

A number of design improvements were made for the second structure;

- The mould tool was improved by going to a 4-point bending scheme.
- The structure skins were reduced to 3-ply to avoid yield during bending of the hinges.
- The number of longitudinal ribs was increased from 4 to 7 in order to provide improved gap control.
- A 50 mm section of each rib either side of the hinge-line was strengthened in order to prevent buckling of these ribs during the folding process.

The resulting second structure shown in Figure 18 was far superior to the first structure in that it maintained its curvature better and held the 20 mm gap between the skins more accurately. In fact 95% of the structure was well within specification for this size of test-piece ( ± 1 mm). The only area out of tolerance was the free edges (extreme ends and edges of the hinge-line).

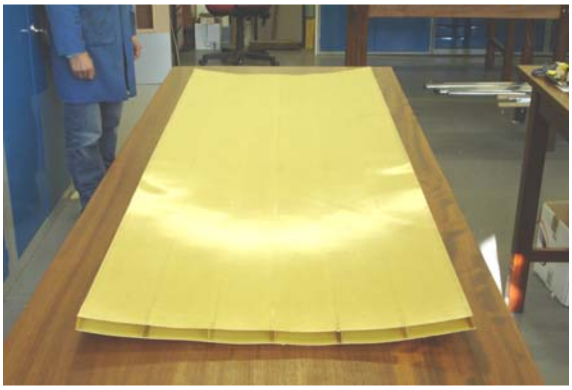


**Figure 18 Completed Second Structure**

The second structure has been successfully folded and unfolded 5 times, see Figure 19, in both directions. The design improvements meant that the folding process was far more robust than that of the first structure. Furthermore, no permanent distortion was found after folding.

(a) (b)

**Figure 19 Folding of second test piece (a) 180 deg. inwards (b) 180 deg. Outwards**

# 7 TESTING

The first test piece was RF tested. Initially the test-piece was 'bench' tested for input return losses and isolation between ports. The assembly was folded and unfolded, and retested. No significant change in RF performance was seen.

The test-piece was then mounted in an antenna range for further RF testing (antenna pattern, gain and cross-polar isolation measurements), see Figure 20. Again the antenna was folded, unfolded and retested. The RF performance did not change. Examples of typical results are presented in Figure 21 and show good correlation between measurements of beam profile before and after deployment.

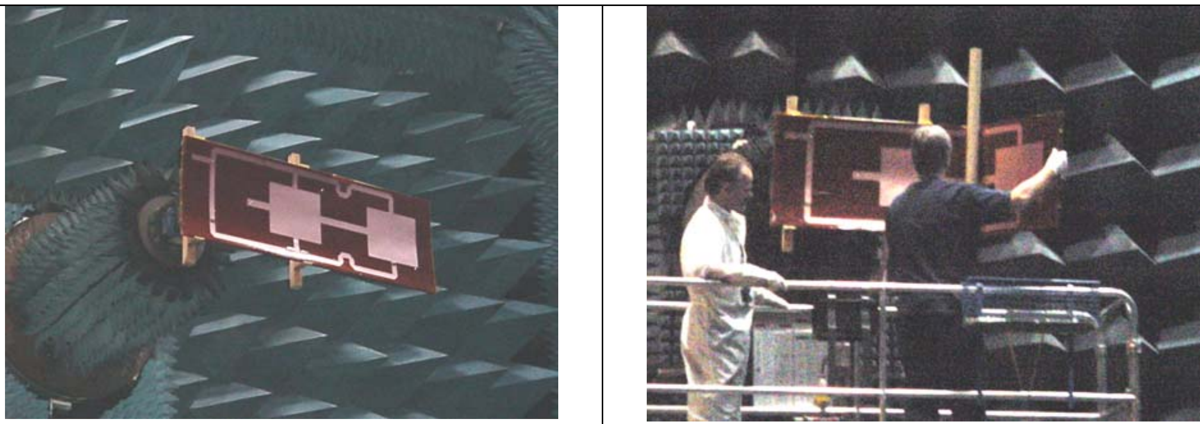
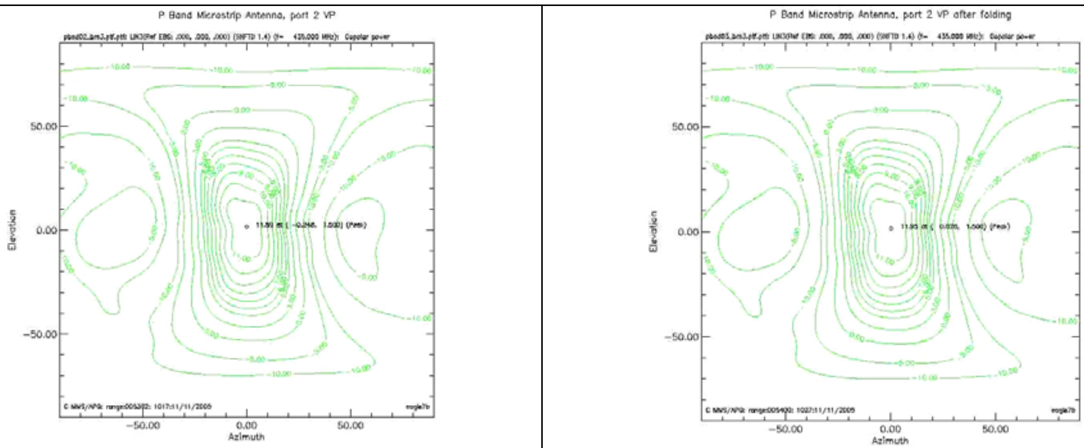


Figure 20 Antenna range testing of first test piece; showing the test piece being folded




| Pre-Fold Pattern:<br>Directivity = 12.61dBi<br>Gain = 11.89dBi ±0.25dB (error)<br>Gain standard antenna = LPDA | Post-Fold Pattern<br>Directivity = 12.63dBi<br>Gain = 11.95dBi ±0.25dB (error)<br>Gain standard antenna = LPDA |
|---|---|
| (a) | (b) |

Figure 21 Typical results from the first test piece; (a) pre-fold pattern: (b) post-fold pattern

# 8 DISCUSSION

The design concept of this antenna structure is based on the shape and properties of a tape-spring. The key structural aspects are to achieve the required stiffness and structural stability while being flexible enough to be able to fold the structure without damage or change in the RF performance. The design feature of the unidirectional ribs being interrupted at the hinge-lines is key to achieving both the stiffness and the folding.

Future mechanical work should look at the choices of material, particularly the rear face sheet that doesn’t need to be RF transparent if the metallised layer is on the top. A full design optimisation exercise will need to be undertaken in order to further minimise the mass. A deployment scheme will need to be selected and demonstrated.

# 9 CONCLUSIONS

A monolithic array using a Folding Large Antenna Tape-Spring (FLATS) structure has been identified as the design with the highest potential for large low frequency antennas. The overall antenna design has 5 rows with 28 elements per row, covering an area of 2.82 m by 17.29 m (approx. 50 $m^2$), split into two equal wings of 5 rows by 14 elements. The continuity of the proposed monolithic antenna design is a very desirable feature, as it avoids the complexity and expense of providing RF transmission across the gap of a more traditional hinge design.

The design uses a curved FLATS structure which follows the basic principle of a tape spring that can be folded flat and Z-folded, yet it springs back to its original, undamaged shape on release. The energy required to fold the structure is stored as elastic strain energy in the structure and is used as the deployment energy. A deployment control system is yet to be designed.

Test pieces have been made to demonstrate both the RF and mechanical aspects of the design, particularly the RF performance before and after folding the structure.

This study has investigated different technologies that might be considered for use in a large, low frequency SAR antenna. The potential for a low mass, low cost, simple and reliable design offered by the FLATS design was recognised in the trade-off study. The design itself has been investigated both analytically and via test-pieces and has been shown to be a viable solution to the problems posed by such large antennas.

## ACKNOWLEDGEMENTS

The work presented in this paper was part of an ESA funded study of antenna technologies suited to operation at low frequencies for global measurement of biomass (Contract No. 18120/04/NL/FM under GSTP, Project Manager Mr Peter Rinous). The project team was led by EADS Astrium Ltd (Project Manager David Hall) and included BAE Systems ATC, the Centre for Terrestrial Carbon Dynamics at Sheffield University, and the Deployable Structures Laboratory at the University of Cambridge.

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# A SPACE BASED RADAR ANTENNA CONCEPT TO COUNTER CAMOUFLAGE AND CONCEALMENT

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# Introduction

- Global surveillance is a key parameter in achieving international security.

- Hostile elements respond by using camouflage and concealment, such as the forest canopy.
  - nullifies the use of optical observations
  - Infer-red (heat sensor) observations from space suffer from poor resolution, and are impeded by cloud and humidity

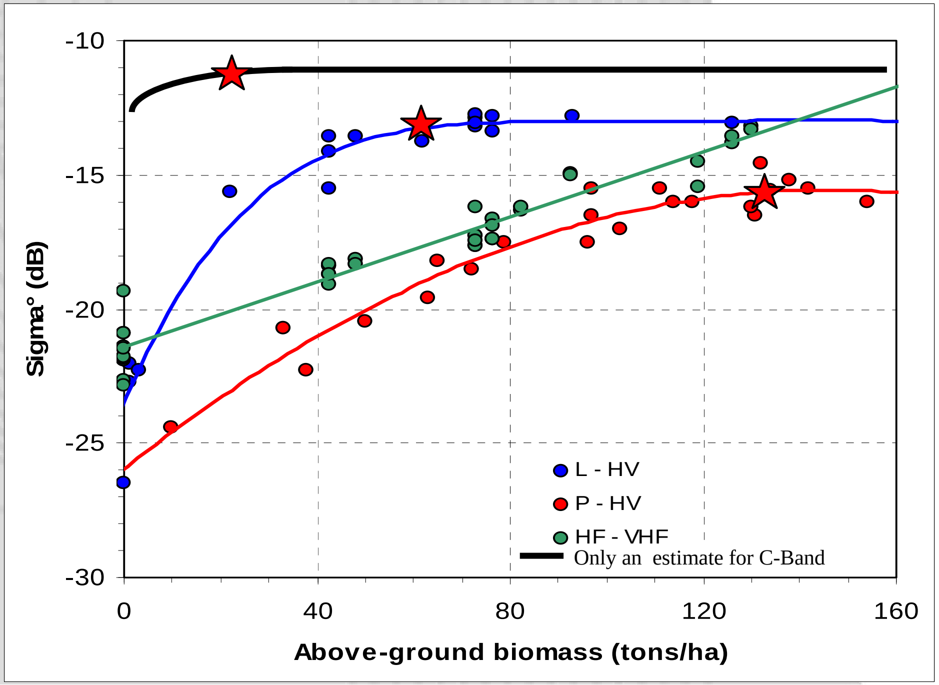
- The solution would seem to be radar observations

# Synthetic Aperture Radars

- Existing radar observations, (X-, C- and even L-band) can not penetrate the majority of forests.

- Density of boreal forests
  - Maximums of ~120 tons/ha (even denser for rain forests)
  - Average of ~50 tons/ha

- Graph shows the reflected signal strength for different radar frequencies;
  - Note 'saturation' point, hence signal no longer penetrate the forest.




What is needed is a Low Frequency SAR antenna



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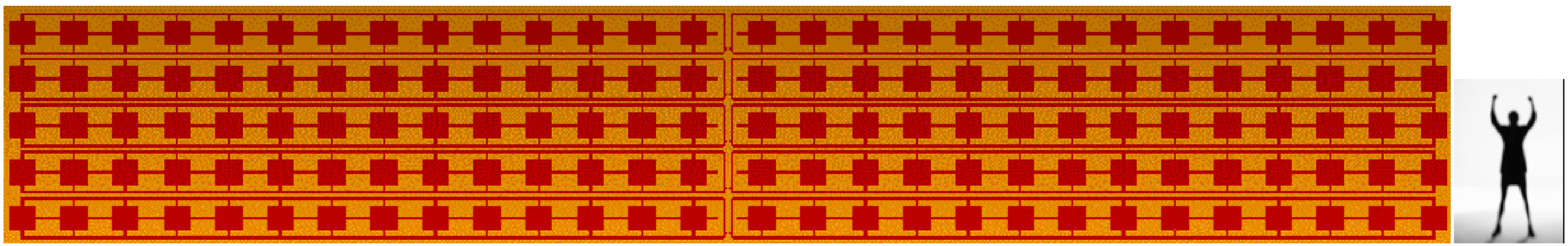
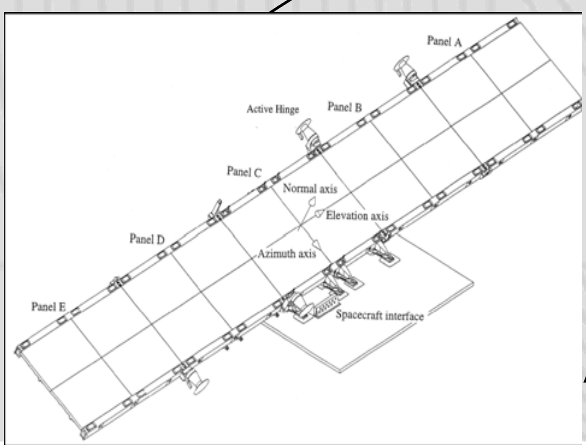
# What size of low frequency antenna?

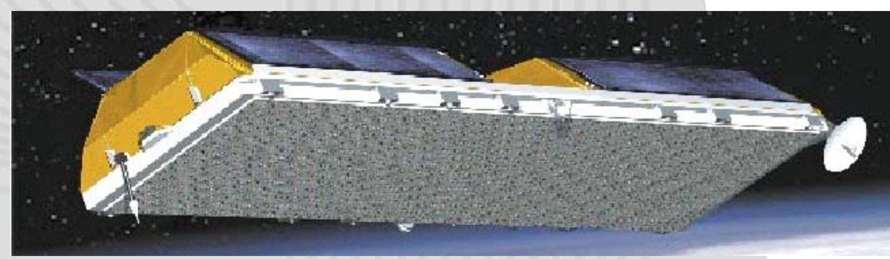
- SAR performance equation;



P-band antenna (0.435GHz)
30m x 3.3m, or **100m²**




ASAR C-band (5.3GHz)
10m x 1.3m, or **13m²**



TerraSAR-L (1.25GHz)
11m x 2.86m, or **31m²**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# Antenna Requirements

- By limiting the angle of incidence a slightly smaller antenna be used;
  - 50m² P-band SAR can scan between 20 - 30º, (20 – 40º for the 100m²)
  - This doesn't affect the quality of the data, only the time taken to achieve global access (from 11 to 20 days).
- Antenna requirements for a 630 km altitude circular orbit;
  - P-Band (0.435 GHz) antenna of 50m², 2.82m high 17.3m long
  - Quad Polar operation;
    - transmitting on H- or V- and receiving simultaneously on both
  - Deployed natural frequency >0.5 Hz, (goal of 1 Hz)
  - Deployed Planarity better than 40mm
  - Stowed volume compliant with low cost launchers (Rockot or Soyuz)
  - Mass target of < 1kg/m²



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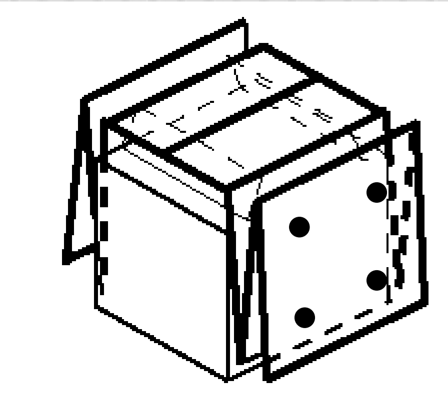
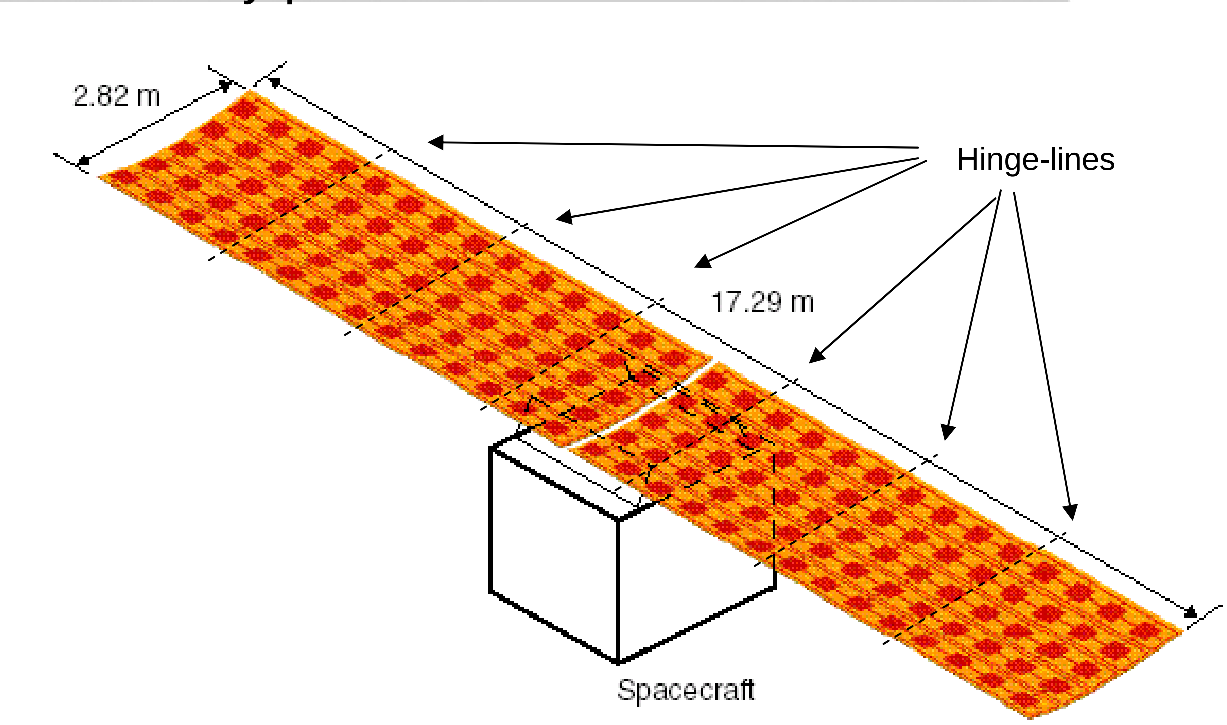
# Design Solution

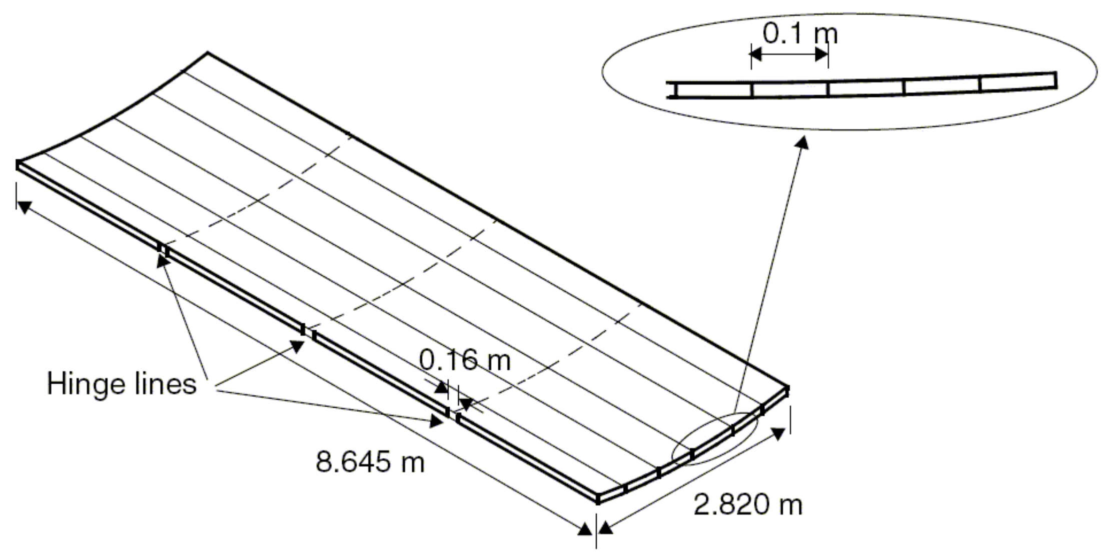
- A Monolithic array with 5-rows of 28-elements per row
- Based on a Folding Large Antenna Tape Spring (FLATS) structure
  - Antenna is designed in 2 halves, but otherwise a continuous structure
- Planar beam produced by phase correction at each row





# What is a 'FLATS' design

- A transversally curved sandwich plate structure forming a giant Tape Spring
- Tape Spring shape provides a significant increase in stiffness, yet can be folded
- One sheet 8.64m by 2.82m would not be stiff enough, however;
  - RF design requires 2 sheets, 20mm spacing, (signal & ground planes).
  - Classic honeycomb core replaced by longitudinal ribs.
  - Hinge-lines where ribs are interrupted and face-sheets bend like a tape measure.
  - Folding stores potential energy to create a self deploying structure.
  - Tape shape locks structure into place on deployment.



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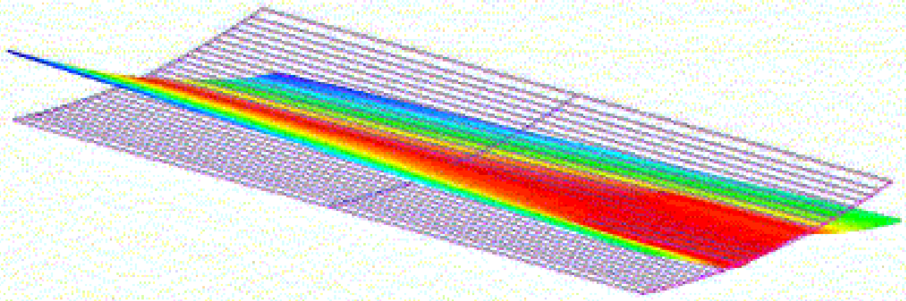
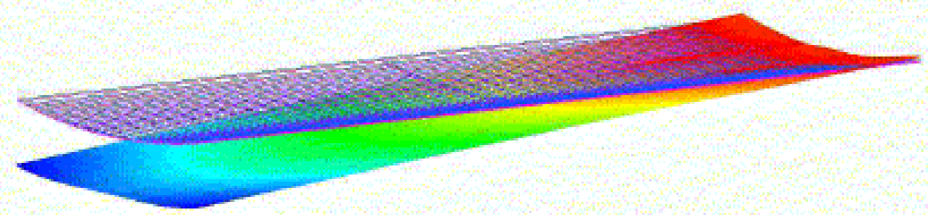
# Structural Analysis

- Deployed structure analysed using a FEM of one wing
  - 4-ply plain–weave Kevlar lay-up (RF transparent)
  - Held at external ribs in first quadrant, used to mount to spacecraft
  - Deployed frequency of 0.9 Hz, close to goal of 1Hz
    - Further design optimisation of shape & materials should give >1Hz



(a)



(b)



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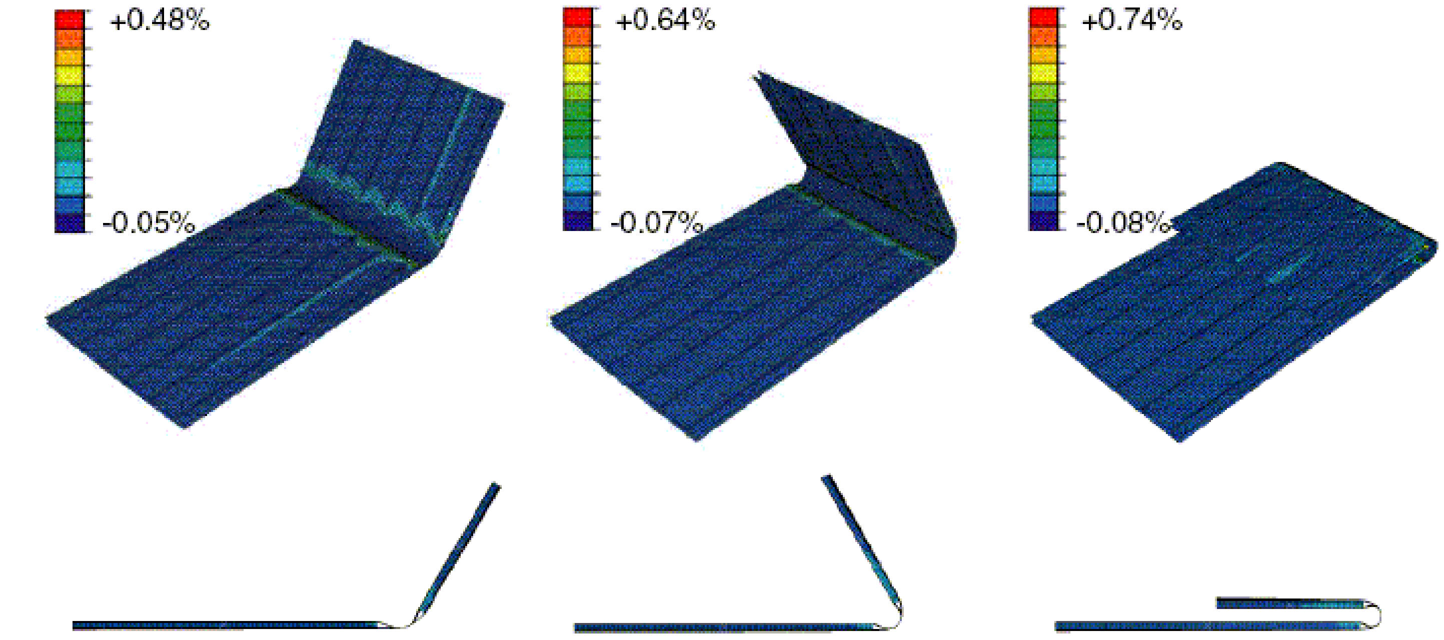
# Structural Analysis

- An analysis of the hinge-line folding process was performed
  - Folding process in two stages, “flattening” and “Z” folding
  - Flattening stresses (12 MPa) & strain levels (0.03%) are low
  - The 180º folding and the resulting strain levels are shown below

<u>Kevlar 49/ 934 weave</u>

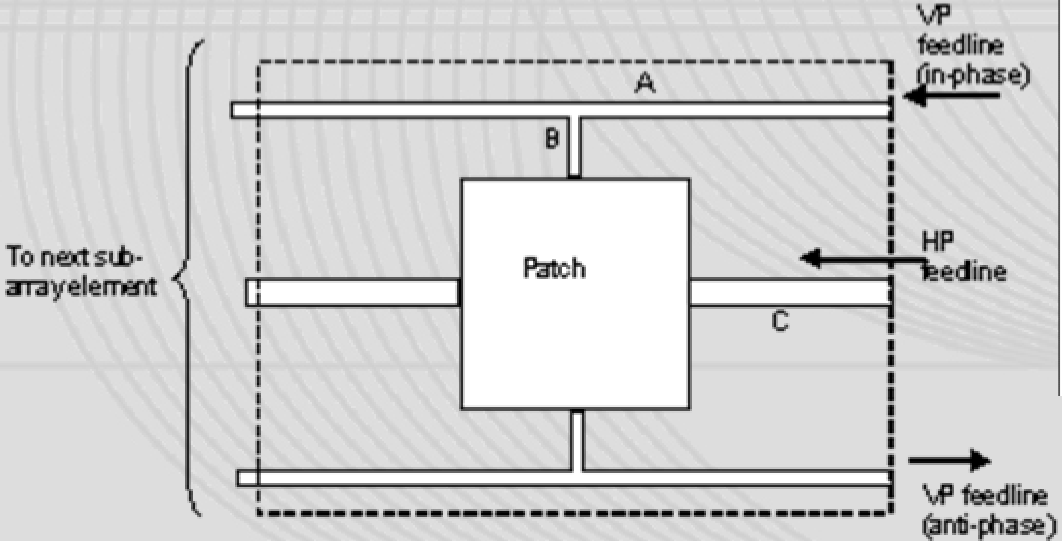
Tensile strength (Ult.)
500 MPa  (1.4% strain)

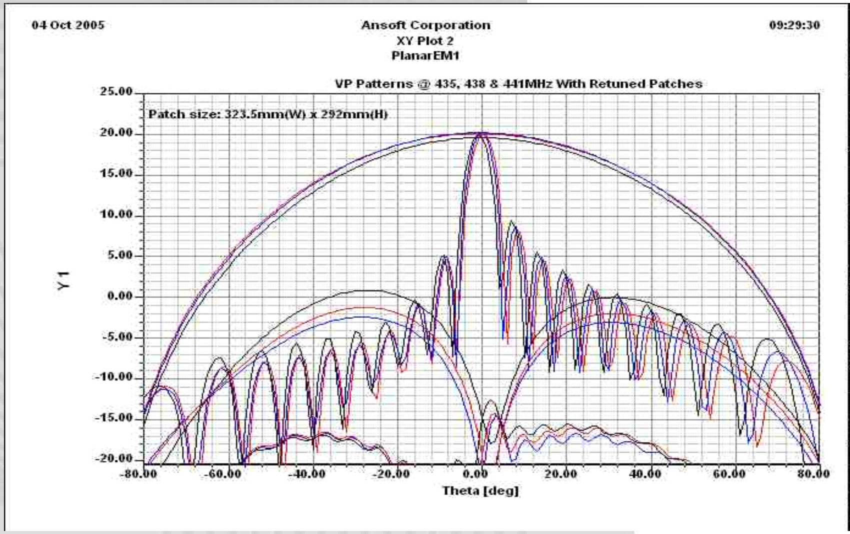
Compressive strength
250 MPa  (2.2% strain)



# RF Design of Monolithic sub-array

- The sub-array design is symmetric with a balanced VP feed
- Design gives a low X-polar response over main sub-array lobe
- High isolation between HP and VP feed ports



# Ionospheric Issues for Low Frequency SARs

- Influences the ability to focus the SAR echo data
  - At maximum TEC (Total Electron Count), along track resolution will be degraded as well as the side-lobe ratios
  - Narrow bandwidth allocation and relatively coarse resolution alleviate most of these focusing issues
  - Auto-focusing techniques can be applied to ‘correct’ the data
    - E.g. Sub Aperture Processing of the Synthetic Aperture

- Ionospheric effects cause polarisation plane rotation (Faraday Rotation)
  - With P-band operation, a Faraday Rotation correction methodology will be required
  - The recommendation is the use of fully coherent quad polar observations enabling measurement of the rotation and its correction



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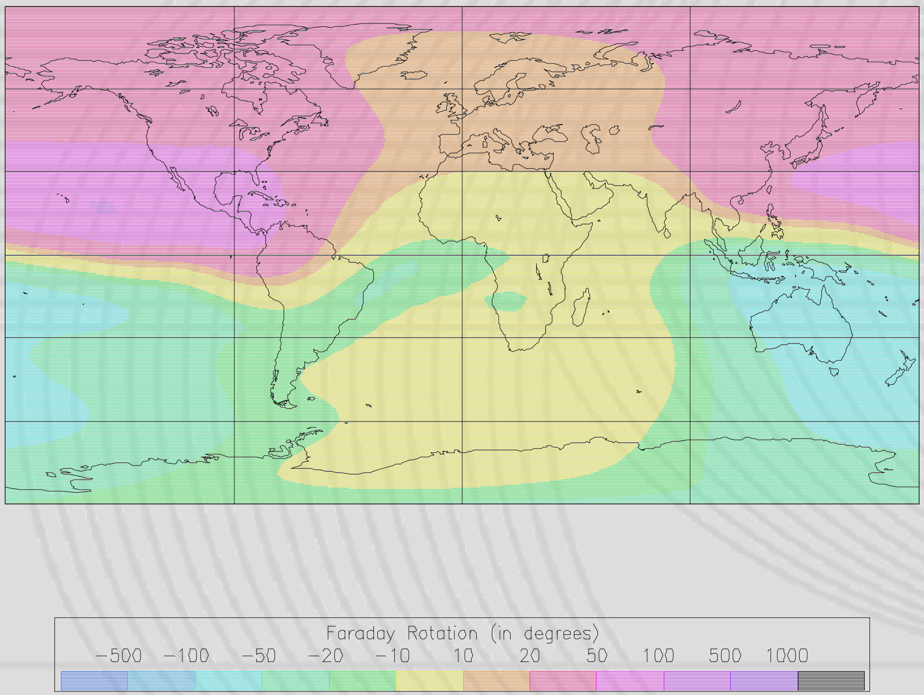
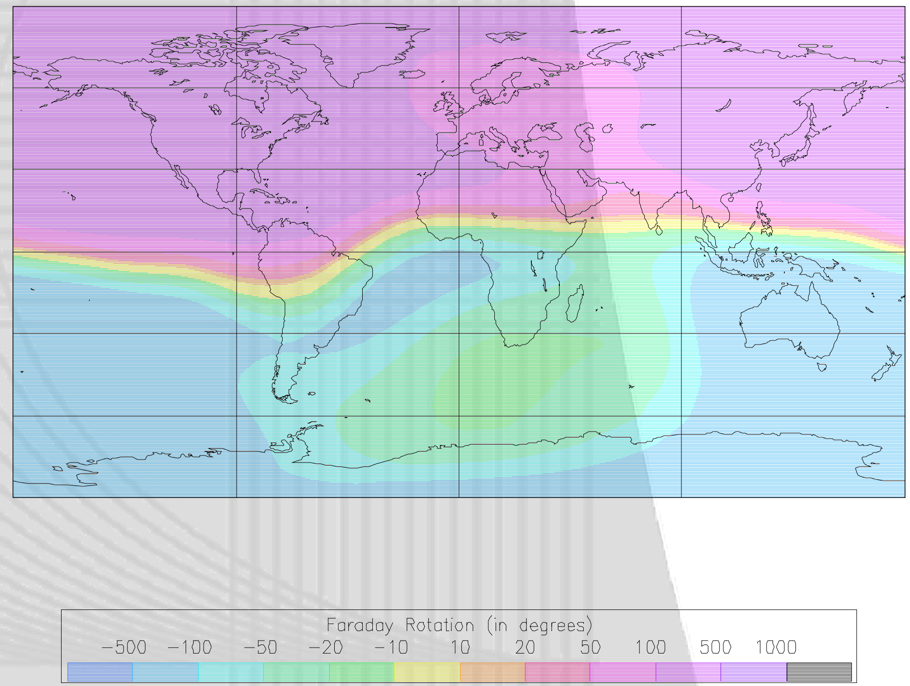
# Ionospheric Issues with Low Frequency SAR

- Faraday Rotation at periods of Low and High TEC activity



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# Test-piece Design, single row of 2-elements

- 1.563m long by 0.564m wide with 30mm curvature depth
- Structure made of Kevlar so that it is RF transparent
- Structure includes a hinge-line
- Etched copper circuit and ground plane added



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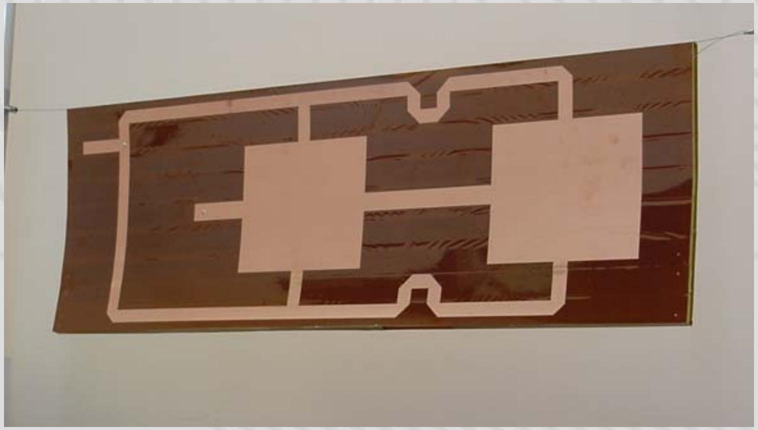
# Test-piece manufacturing

- Curved skins made and Structure bonded together on a mould tool
- Hinge-line tested on structure
- RF circuit bonded to front skin
- Ground plane bonded to rear surface & RF connections made.

- Measured mass,
  1.0kg, or 1.13 kg/m²
- Measured accuracy,
  ±0.5mm over 95%



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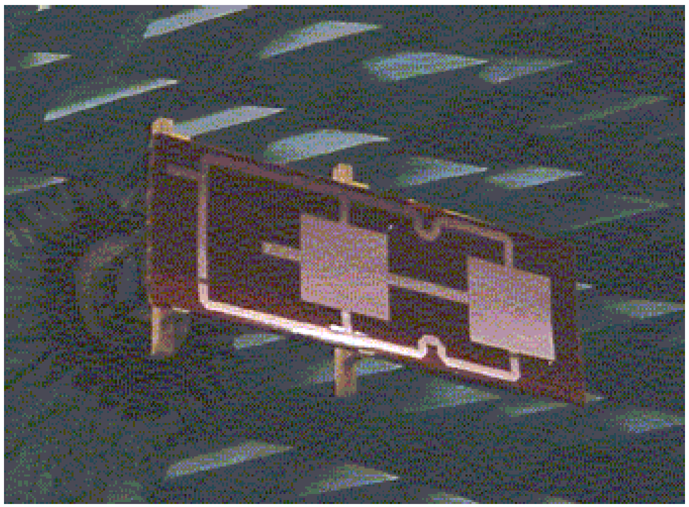
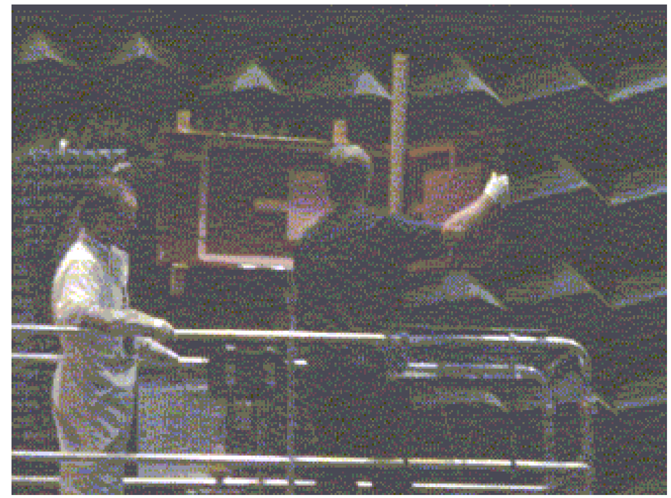
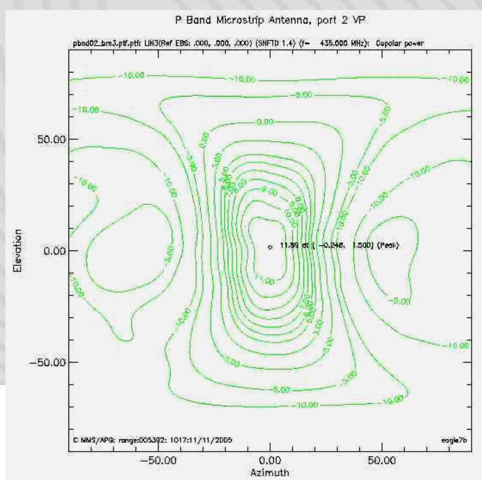
# Test-piece Testing

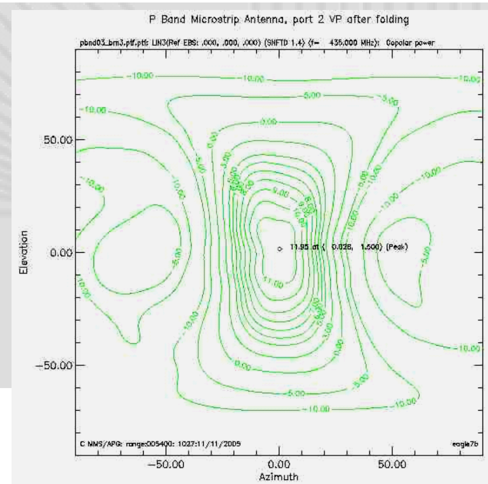
- Key test was to RF test the antenna before folding, then retest after folding;
  - RF testing of return loss, antenna pattern, gain and cross polar isolation





**Pre-Fold Pattern:**
Directivity = 12.61dBi
Gain = 11.89dBi
±0.25dB
Gain standard
antenna = LPDA




**Post-Fold Pattern:**
Directivity = 12.63dBi
Gain = 11.95dBi
±0.25dB
Gain standard antenna
= LPDA

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# Conclusions

- P-Band SAR observations can penetrate forests, enable searches for buildings hidden beneath forest canopies, and possibly penetrate the earth in search of tunnels and caves
- A unique **F**olding **L**arge **A**ntenna **T**ape **S**pring (**FLATS**) structure is identified as having the best potential for a large Low Frequency SAR
- Design and analysed has been performed for a 50m² P-band antenna
- Test-pieces manufactured and tested to confirm key design factor;
  - RF testing before and after folding hinge-line showed excellent repeatability
- Work was performed under ESA GSTP funding of low frequency antennas for global measurement of biomass (Contract 18120/04/NL/FM);
- Further work is required to determine and demonstrate a Deployment system

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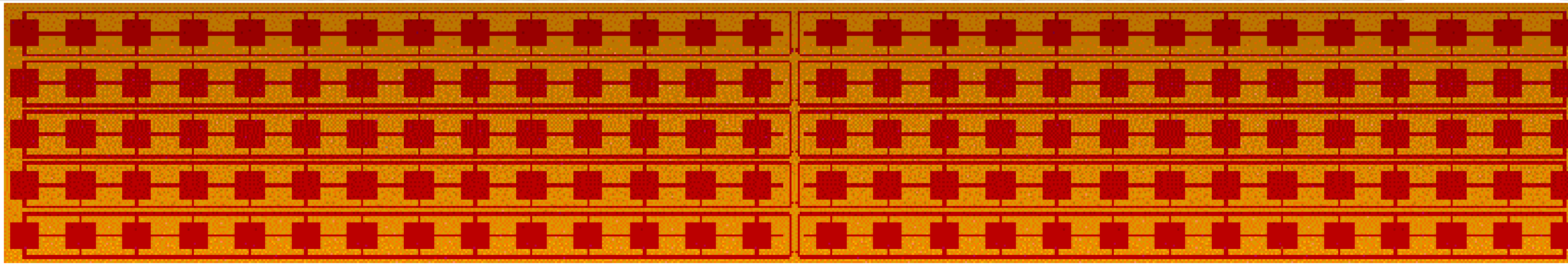

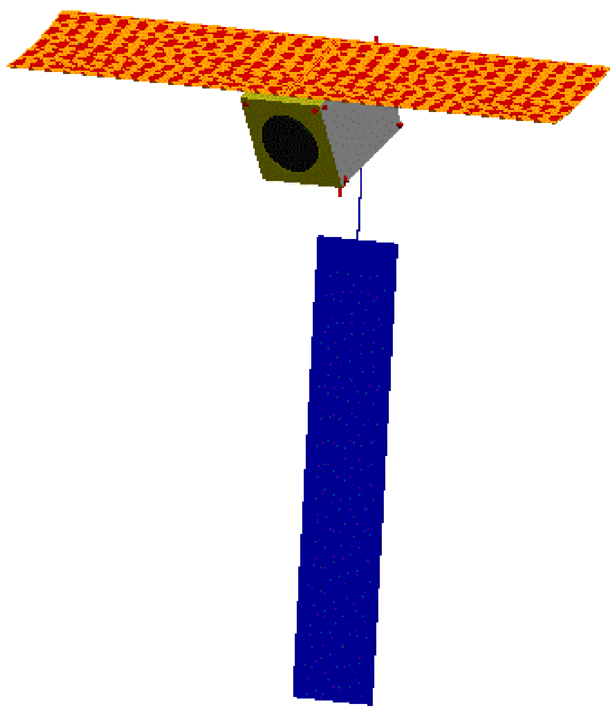

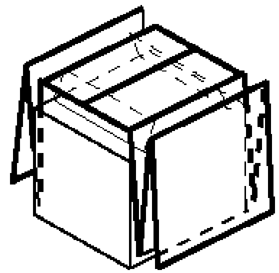

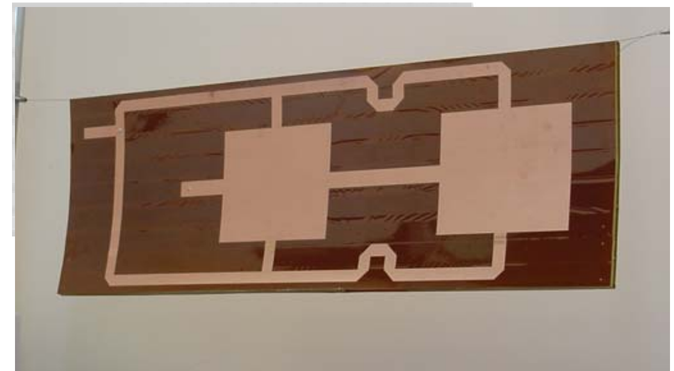

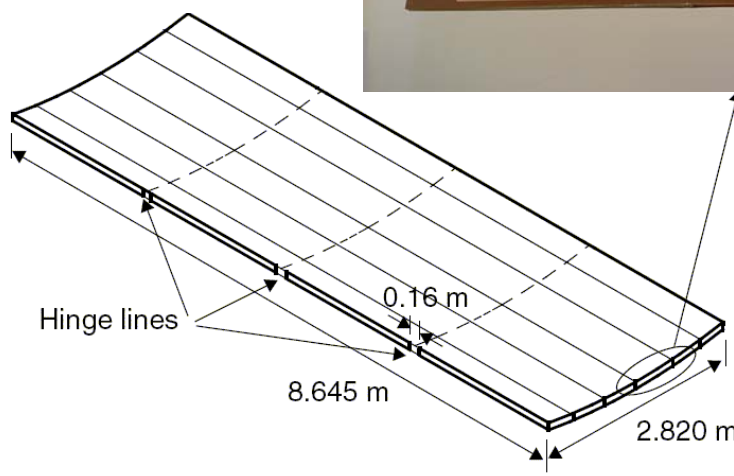


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